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Topographic reconstruction: a geomorphic approach

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Abstract

The landscapes manufactured during disturbed-land reclamation are the foundations for all subsequent reclamation practices and the surfaces for future land uses. From a geomorphic perspective, the goal of topographic reconstruction is the creation of steady-state landscapes. As the reconstructed drainage basins, hillslopes, and stream channels approach steady-state configurations, adjustments by geomorphic processes after reclamation decrease. As the adjustments necessary to establish the steady state decrease, the prospect for reclamation success increases and the demand for post-reclamation site maintenance decreases. Digital elevation modeling software offers an opportunity to incorporate geomorphic principles into topographic reconstruction at the design stage of reclamation. As a first approximation, drainage-basin area, weighted mean slope, and drainage density for the pre-disturbance or undisturbed landscape are closely replicated in the reconstructed topography. The technical and economic feasibility of this approach is currently being tested.

Keywords: Manufactured landscapes; Geomorphic reclamation goals; Geomorphic design principles; Digital landscape design

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1. Introduction

Under natural conditions, geomorphic processes usually sculpt the land surface of the earth into drainages basins, each of which is composed of hillslopes and stream channels. These drainage basins function as open, process-response systems for the efficient transportation of water and sediment. Changes in water and sediment inputs result in changes in water and sediment outputs, sometimes with concomitant changes in the morphologic characteristics of hillslopes and stream channels to the extent necessary to maintain efficient operation of the systems.

Under natural conditions, an approximate steady-state or dynamic equilibrium prevails within drainage-basin systems. With approximate balances among forces and resistances, geomorphic processes operate at low rates. Hence, changes in morphologic characteristics are slow over long time periods as often demonstrated by photographs of the same landforms taken decades apart. There is no on-site or off-site degradation of the environment as long as the steady-state prevails.

Disturbances to the steady-state of drainage-basin systems result in various imbalances among forces

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and resistances, causing geomorphic processes to operate at accelerated rates. These processes may work to re-establish the previous steady-state, with morphologic characteristics of hillslopes and stream channels that are similar to those of the past. Alternatively, the processes may work to establish a new steady-state, with new morphologic characteristics of hillslopes and stream channels. During this period of adjustment and accelerated process rates, drainage-basin surfaces experience mass-instability and dissection by erosion processes. Large amounts of sediment are produced, transported off-site, and deposited in streams, lakes, and reservoirs. On-site and off-site environmental degradation occurs rapidly, and collectively may affect areas many times the size of initial land disturbance. Eventually, geomorphic processes restore a steady-state, but this may take hundreds of years.

2. Geomorphic goals for land reclamation

From a geomorphic perspective, the goal of topographic reconstruction is a steady-state landscape with approximate balances among forces and resistances. These landscapes are composed of drainage basins again functioning as open process-response systems with efficient flow of water and sediment, geomorphic processes operating at low rates, no on-site or off-site environmental degradation, and are capable of sustaining productive post-reclamation land uses.

Unfortunately, it is not possible to construct landscapes in a perfect steady-state. Geologic structures are permanently destroyed by many types of disturbances. Soils consolidate and soil-structures regenerate over decades. Vegetation root networks and foliage develop over several years. Nevertheless, landscapes that approximate steady-state configurations experience less modification by geomorphic processes after reclamation than landscapes that do not approximate steady-state configurations. As the adjustments necessary to establish a steady-state decrease, the prospect for reclamation success increases and the demand for post-reclamation site maintenance decreases. Hence, the practical goal of land reclamation is the reconstruction of landscapes that approximate a steady-state configuration.

3. The reclamation process

The reclamation process consists of 10 sequential steps: (1) site characterization, (2) reclamation planning and engineering, (3) material management, (4) topographic reconstruction, (5) replacement of topsoil or soil substitute, (6) surface manipulation, (7) addition of soil amendments, (8) revegetation, (9) irrigation, if needed, and (10) site monitoring and maintenance (Toy and Daniels, 2000). Topographic reconstruction is an essential part of high-quality reclamation because the resulting landscapes are the foundations for all other reclamation practices and the surfaces for future land uses. Other reclamation goals, such as sustained agricultural production or wildlife habitat, are impossible without geomorphically stable landscapes.

3.1. *Traditional topographic reconstruction*

The traditional approach to topographic reconstruction primarily consists of the grading and shaping of spoil (i.e. waste rock). Hillslopes and stream channels are constructed without much thought concerning their integration into functional drainage basins as open, process-response systems. The first objective is mass stability of the unconsolidated spoil. Stability analyses for hillslope design commonly are based upon the equilibrium of forces and resistances along a two-dimensional “slice” through the hillslope, selected along the potential failure surface. In general terms, hillslope stability increases as hillslope gradient decreases, hillslope height decreases, and pore-water pressures decrease.

Once mass stability is achieved, the next objective is erosion control. Relations between hillslope shape and erosion rates are well-documented (Toy and Hadley, 1987; Meyer et al., 1975). Estimates of erosion-rate for hillslope design can be based upon prediction technologies such as the Revised Universal Soil Loss Equation (RUSLE) (Toy and Foster, 1998). In general terms, erosion rates decrease as hillslope steepness decreases and as hillslope length decreases. In addition, concave hillslope profiles are less erodible than convex profiles.

The morphology of natural channels is determined by water and sediment discharges (Schumm, 1977). The morphology of reclaimed channels, however, is determined by channel engineering and construc-